THE INFLUENCE OF ANXIETY OF PUPILLARY BEHAVIOR

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THESIS

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ABSTRACT

The Stroop color-word test was used as an anxiety provoking situation, in an attempt to isolate the effects of such anxiety on pupillary behavior. A TV Pupillometer was utilized to measure the pupil diameter during testing. Although the confrontation with the anxiety provoking situation did produce the anticipated pupil dilations, the data was felt to be contaminated by a confounding variable and the high variability attributed to the subjects. As a result, no conclusive evidence was obtained to either support or repute the association of anxiety with the observed pupillary reactions. The results are significant, in that the commonly accepted association of anxiety and pupillary dilations was not supported.

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I. INTRODUCTION

The experimental work of Hess and Polt (1960, 1964; Hess, 1965) stimulated an upsurge of interest and, consequently, a significantly increased research effort dealing with pupillary behavior. The trend of this recent research has been to explore the variables which induce the pupillary activity as controlled by the sympathetic division of the autonomic nervous system rather than the more easily understood reflexive activity to light which is controlled by the parasympathetic division. From this exploration has come a wealth of evidence indicating that a wide variety of nonvisual processes influence pupillary activity. Most significant among these processes are:

1) cognitive processes (e.g., Paivio and Simpson, 1966; Kahneman and Beatty, 1966, 1967; Payne, _et al_, 1968; Carver, 1971)
2) emotional processes (e.g., Holmes, 1967; Koff and Hawkes, 1968; Nunnally, _et al_, 1967; Barlow, 1969; Tanck and Robbins, 1970)
3) sensory processes (e.g., Yoss, _et al_, 1970; Nunnally, _et al_, 1967).

Prior to the contributions of Hess and Polt, investigation of pupillary responses to other than light stimuli and the results of these investigations had remained in relative obscurity. Of particular interest to this study, among the early work, is that of Bumke (1903), of which Gang (1945) commented that "forty years

prior Bumke had accurately described the phenomenon of sustained dilation in the presence of anxiety." Possibly because little pupillary response research in this area was conducted between the time of this observation by Gang, and the publications of Hess and Polt, unquestioned acceptance of this sentiment has evidently persisted in the more recent research. Bernick and Oberlander (1968), with reference to Gang (1945), state, "It is generally accepted that anxiety produces a dilation of the pupil." Perhaps because of such general acceptance as this, the relationship between anxiety and pupillary dilation appears to have been largely ignored in recent research.

Exceptions are found in the work of Bernick and Oberlander (1968), Kahneman and Peavler (1969), Kahneman and Beatty (1967), Nunnally, et al (1967), Polt (1970), and Carver (1971). Although these authors do consider anxiety as a contributing factor in pupillary dilation responses, their primary concern and experimental objectives have been focused on other dilation response stimuli. Anxiety has, therefore, only been recognized in recent research as a confounding variable and has not been studied under the scrutiny of modern equipment and investigative procedures.

It is not the intent here to cast doubt on the validity of previous findings, but to suggest that in view of the results of recent research, the isolation of the specific causative factors of dilation is extremely important. Because of the close association of cognitive, emotional, and sensory processes, it is certain that many interrelationships exist in pupillary responses induced by various stimuli. The validity of recent studies necessarily rests

on a determination of the degree of involvement of contributing factors such as anxiety. Recognition of the need for more experimental data relating the effects of anxiety and pupillary responses has previously been voiced by Carver (1971).

Thus, it is the intended purpose of this study to:

1) Attempt an isolation of the effects of anxiety on pupillary responses.

2) Attempt to establish a correlation between the magnitude of pupillary dilations and an accepted measure of anxiety.

The Stroop (1935) color-word test will be employed as an anxiety provoking situation of proven reliability. The Taylor (1953) Manifest Anxiety Scale (MAS) will be administered to provide a ranking of anxiety among subjects.

It is hypothesized that upon initially encountering the incongruous color-word combinations of the Stroop test, a significant increase in the peak magnitude of a subject's pupil diameter will be observed.

Because of the persistancy of anxiety provoked pupillary dilations (Gang, 1945), it is expected that a sustained dilation will be observed following presentation of the anxiety provoking situation.

Additionally, it is anticipated that the relative magnitude of this increase will be predictable on the basis of the subject's relative ranking on the anxiety scale.

II. EXPERIMENTAL METHOD

A. APPARATUS

The apparatus consisted of a Space Sciences Incorporated, Model 830 TV Pupillometer and a Lafayette Instrument Company, Model 2303D, memory drum.

The TV Pupillometer is made up of a closed circuit television system and a signal processor, which provide continuous observation of the eye. Measurements of pupil diameter are made continuously and are permanently recorded on an integrated chart recorder. A multipurpose mounting is utilized for the TV camera, a near-infrared illumination source, and an adjustable chin rest and forehead restraint.

The memory drum was adjusted so that stimulus presentation would occur at eye level at a distance of thirty inches. The rotational speed of the drum was set to provide a stimulus presentation rate of one word every 1.4 seconds with a presentation duration of 0.7 seconds.

The entire apparatus was located on a table in a corner, and a curtain shielded the subject from all visual distractions. This curtain slightly reduced the illumination level, but not enough to affect visual discrimination.

Experimentation was conducted at the Human Engineering Laboratory of the Naval Postgraduate School, Monterey, California.

B. SUBJECTS

The subjects were 30 male officer students at the Naval Postgraduate School who served as subjects on a voluntary basis. Potential subjects were screened for visual deficiencies, and those who were required to wear glasses or were color blind were rejected.

Nine subjects were eliminated whose pupil measurements were considered inaccurate due to head or eye movement after the commencement of testing or due to experimenter inconsistencies. The ages of the test group ranged from 25 to 33 years.

C. STIMULI PRESENTATION

The stimuli for the Stroop test consisted of three lists using the four words, "black", "blue", "red", and "green". Each word appeared in a random order four times on each list. Lists 1 and 3 were composed of congruous color-word combinations, while the words of list 2 provided 12 incongruous and 4 congruous color-word combinations. In list 2, the initial three words and the thirteenth were congruously colored. (The lists appear in Appendix A.) The specific colors were chosen as they represent the three broad spectural color band divisions and the lack of color.

Each stimulus word presentation will be referred to as a trial.

The beginning of each list of words was preceeded by a countdown sequence of numbers from five down through zero.

D. TESTING PROCEDURE

Upon entering the laboratory, subjects were given a set of instructions (Appendix B) to read and were subsequently briefed by the experimenter on the general operation of the equipment and the

necessity for limiting head movement. This briefing period provided an interval for the adaptation of the subject's eyes to the illumination level. It also served as an interval for stabilization or alleviation of anxiety provoked dilations due to apprehension about the equipment.

All queries by the subject were truthfully answered except those relative to the specific content of the stimulus material. Replies to these questions were deferred until the post-test debriefings.

When the subject felt he sufficiently understood the instructions, he was asked to place his head as comfortably as possible in the head holder. The TV camera was then adjusted to obtain a picture which would allow the proper discrimination necessary for accurate and responsive electronic measurements.

Following the adjustment of the pupillometer, presentation of the three lists of words was begun. The lists were selectively presented by the opening and closing of appropriate slots on the memory drum.

Once testing was begun, no further adjustments of the Pupillometer were made as this may have affected the accuracy of measurement.

Auditory stimulation during testing was held to the sounds of the chart recorder and the memory drum.

During testing, the experimenter recorded the responses of subjects and made markings on the chart record to correspond with the presentation of the six countdown numbers and the Stroop test stimuli. These markings served to synchronize the chart record of

pupillary response and the initiation of visual stimuli. This sychronization was accomplished by utilizing an event entry key which is a feature of the pupillometer used.

After completing the presentation of the word lists and prior to revealing the purpose of the experiment, subjects were asked to complete the short form of the MAS.

III. RESULTS

A. DATA REDUCTION

Two measurements of pupil diameter for each trial were obtained from the chart recording. A maximum diameter measurement was made for each interval during which the visual stimulus was in view, and a minimum diameter measurement was taken from the interval between successive maxima.

If a peak magnitude measurement was followed by an eye blink, which obscurred accurate minimum diameter measurement, the average of the two adjacent minimums was used. All diameters were measured in millimeters directly from the chart recording scale. The resulting measurements were consistent with patterns and trends observed during testing and with the observations of previous research in that peak diameters were obtained just prior to the verbalization of the required responses (e.g., Bernick and Oberlander, 1968; Simpson and Paivio, 1968; Kahneman, et al, 1968).

A third measurement, the difference between minimum diameter and the immediately preceeding maximum, was also computed. This measure will be referred to as the differential pupil diameter.

The values for each trial were summed into blocks of four trials for analysis.

This blocking was accomplished primarily to simplify the analysis, but it also served to minimize the effects of random pupil fluctuations.

A summary of the resulting block values summed over subjects is presented in Table I. From these values, the mean pupil diameter was calculated, and these means are displayed in Figures 1, 2, 3.

B. ANALYSIS

The blocked data values for the 21 subjects were analyzed using a treatment x treatment x subject analysis of variance design. This analysis was performed on the list and block variables for each of the three recorded measurements. Tables II, III, and IV give the results of these analyses.

From these tables it can be seen that, while no significant effects were revealed in the analysis of minimum diameter measurements, the other two analyses did detect significantly different effects at the indicated levels. The analysis of the maximum pupil diameter measurements indicated a significant difference due to the list effects. The relationship between lists which accounts for this significant difference is that observed in Figure 1, which shows the average maximum pupil diameter is greater for List II than for either of the other lists and is greater for List III than List I.

The analysis of variance performed on the differential pupil diameter measurements revealed a significant block effect and a significant block x list interaction. This interaction is depicted graphically in Figure 3, and appears primarily to be due to a greater slope for the List III condition, plus the nonmonotonic trend for List II.

From an informal analysis of the number of errors made by all subjects it was concluded that these results were not sufficiently

TABLE I

SUMMATION OF DIAMETER MEASUREMENTS
OVER SUBJECTS

LIST I

	Blocks of Trials			
	(1-4)	(5-8)	(9-12)	(13-16)
MEASUREMENT				
MAXIMUM	395.3	393.3	388.1	383.7
MINIMUM	373.9	373.9	372.2	370.3
DIFFERENCE	19.4	19.4	15.9	13.4

LIST II

	Blocks of Trials			
	(1-4)	(5-8)	(9-12)	(13-16)
MEASUREMENT				
MAXIMUM	405.7	409.2	410.9	405.5
MINIMUM	386.6	388.5	395.2	389.1
DIFFERENCE	19.1	20.7	15.7	16.4

LIST III

	Blocks of Trials			
	(1-4)	(5-8)	(9-12)	(13-16)
MEASUREMENT				
MAXIMUM	405.5	402.2	397.2	397.2
MINIMUM	380.5	378.0	379.4	382.4
DIFFERENCE	25.0	24.2	17.8	14.8

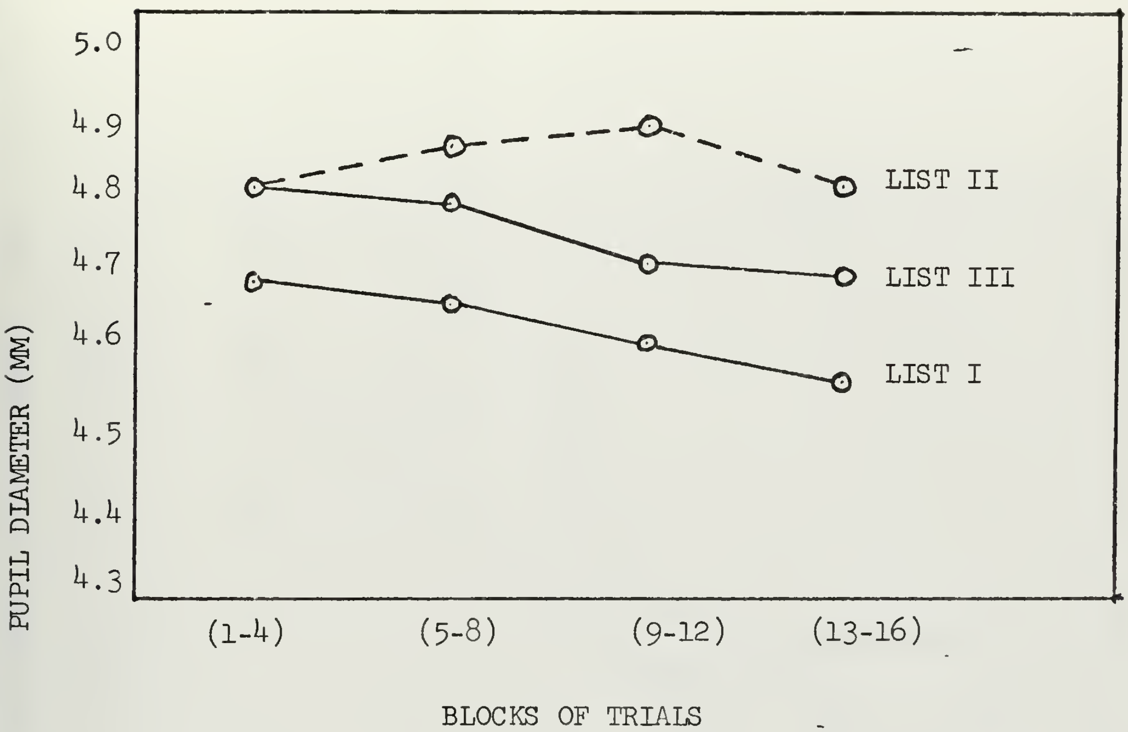

FIGURE 1. Average Maximum Pupil Diameter Per Block

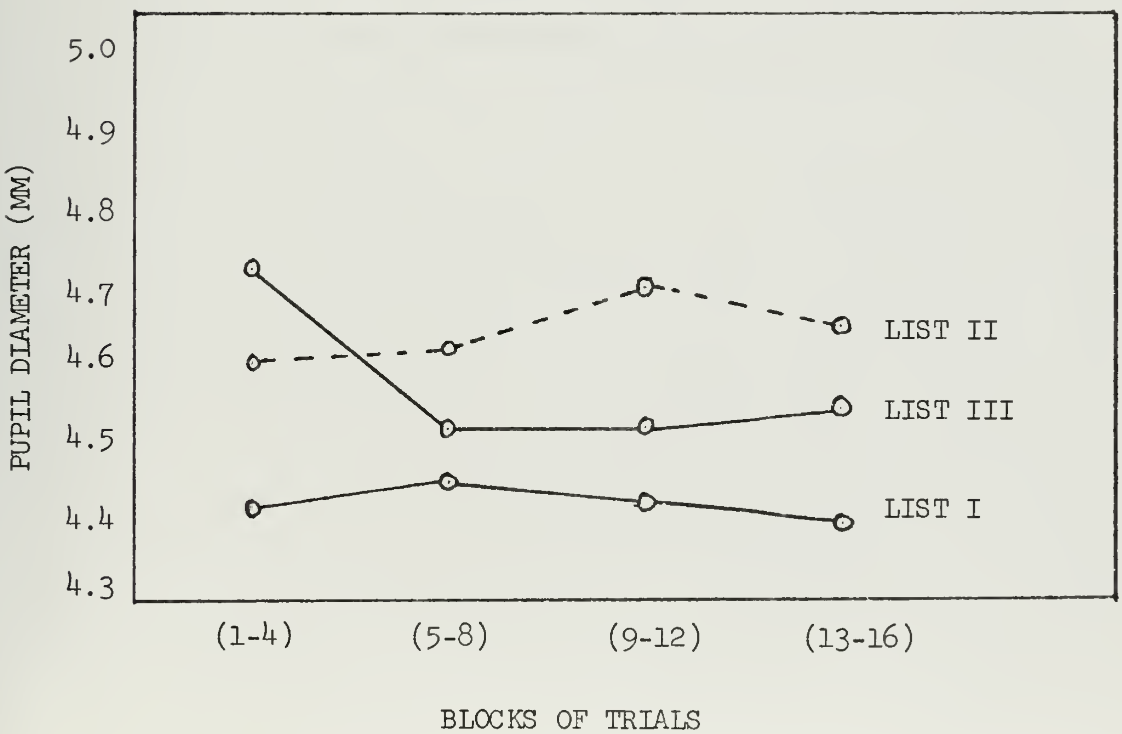

FIGURE 2. Average Minimum Pupil Diameter Per Block

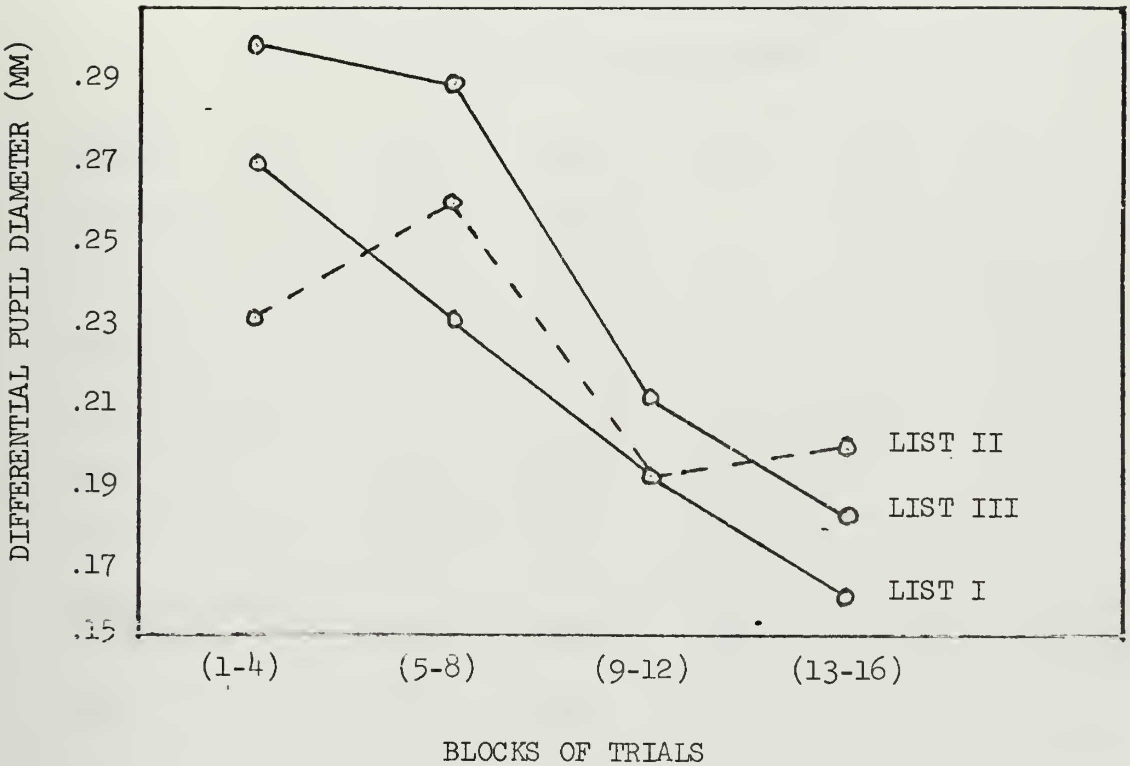

FIGURE 3. Average Differential Pupil Diameter Per Block

TABLE II

ANALYSIS OF VARIANCE ON MAXIMUM
PUPIL DIAMETER MEASUREMENTS

SOURCE	df	SS	MS	F	p
Subjects	20	1359.8			
Lists	2	30.2	15.1	2.3	0.1
Blocks	3	4.0	1.3	1.4	—
Blocks x Lists	6	3.6	0.6	0.5	—
Error Lists	40	264.1	6.6		
Error Blocks	60	46.9	0.8		
Error Blocks x Lists	120	150.6	1.2		
Total	251	1859.2			

TABLE III

ANALYSIS OF VARIANCE ON MINIMUM
PUPIL DIAMETER MEASUREMENTS

SOURCE	df	SS	MS	F	p
Subjects	20	1372.0			
Lists	2	29.8	14.9	1.47	—
Blocks	3	.5	0.17	0.24	—
Blocks x Lists	6	2.2	0.36	1.12	—
Error Lists	40	405.4	10.13		
Error Blocks	60	41.8	0.70		
Error Blocks x Lists	120	38.5	0.32		
Total	251	1890.2			

TABLE IV

ANALYSIS OF VARIANCE ON DIFFERENTIAL
PUPIL DIAMETER MEASUREMENTS

SOURCE	df	SS	MS	F	p
Subjects	20	59.3			
Lists	2	0.8	0.4	0.62	--
Blocks	3	5.8	1.93	12.87	.0005
Blocks x Lists	6	1.0	1.66	11.06	.0005
Error Lists	40	25.8	0.64		
Error Blocks	60	9.1	0.15		
Error Blocks x Lists	120	18.6	0.15		
Total	251	120.4			

varied to provide any meaningful comparison. All subjects incorrectly identified the color on the initial confrontation with the incongruous combination. The number of errors ranged from one to five with a mean of 3.9

The number of eye-blinks, which was available from the chart recordings, was not used in the analysis, as the subjects were asked to attempt to inhibit eye-blinks in order to provide better pupil diameter measurements. Only five of the 21 subjects had recorded eye-blinks during the testing interval.

In order to compare pupillary responses and anxiety scores, scores on the MAS were ranked in magnitude and the subjects with the five high and five low scores were specified as Group I, High Anxiety (HA), and Group II, Low Anxiety (LA). The performance of the groups was then tested using a three-factor, mixed design (repeated measures on two factors), analysis of variance. The results of this analysis for all three measured values are displayed in Tables V, VI, and VII.

These results indicate a significant block x list interaction in the analysis of all three measurements. This effect was felt to be a residual of the similar significant interaction found for the entire group and was not further investigated.

A significant difference in the block effects was also detected in the analysis of the differential diameter measurements and again this was deemed to be a result of the similar effect found in the parent group analysis.

Finally, a significant group x block x list interaction was indicated in the analysis of both the maximum and differential pupil diameter measurements. A graphical display of this interaction is presented in Figures 4 and 5.

TABLE V

ANALYSIS OF VARIANCE ON MAXIMUM PUPIL DIAMETER MEASUREMENTS FOR THE HA AND LA GROUPS

SOURCE	df	SS	MS	F	p
Between Subjects	9	908.2			
Groups	1	230.5	230.5	2.72	.25
Error	8	677.7	84.7		
Within Subjects	110	344.7	12.5		
Lists	2	25.1	0.4	0.86	—
Blocks	3	1.2	22.6	0.36	--
Groups x Lists	2	45.3	0.6	1.56	.25
Groups x Blocks	3	2.0	0.66	0.6	--
Blocks x Lists	6	5.2	0.86	8.6	.0005
Groups x Blocks x Lists	6	2.9	0.48	4.8	.001
Error 1	16	231.9	14.5		
Error 2	24	26.2	1.1		
Error 3	48	4.9	0.1		
Total	119	1252.9			

TABLE VI

ANALYSIS OF VARIANCE ON MINIMUM PUPIL
DIAMETER MEASUREMENTS FOR THE HA AND LA GROUPS

SOURCE	df	SS	MS	F	p
Between Subjects	9	921.6			
Groups	1	212.5	212.5	2.4	.25
Error	8	709.1	88.6		
Within Subjects	110	351.8			
Lists	2	27.4	13.7	0.94	--
Blocks	3	1.2	0.4	0.51	--
Groups x Lists	2	45.7	22.85	1.57	.25
Groups x Blocks	3	3.2	1.06	1.36	--
Blocks x Lists	6	4.6	0.77	2.2	.10
Groups x Blocks x List	6	1.4	0.23	0.66	--
Error 1	16	232.9	14.56		
Error 2	24	18.7	0.78		
Error 3	48	16.7	0.35		
Total	119	1273.4			

TABLE VII

ANALYSIS OF VARIANCE ON DIFFERENTIAL PUPIL DIAMETER MEASUREMENTS FOR THE HA AND LA GROUPS

SOURCE	df	SS	MS	F	p
Between Subjects	9	35.4			
Groups	1	0.4	0.4	0.09	--
Error	8	35.0	4.4		
Within Subjects	110	24.1			
Lists	2	0.7	0.35	0.8	--
Blocks	3	2.8	0.93	4.97	.01
Groups x Lists	2	0.7	0.35	0.82	--
Groups x Blocks	3	0.2	0.07	0.35	--
Blocks x Lists	6	0.5	0.8	6.7	.0005
Groups x Blocks x Lists	6	2.2	0.37	3.1	.025
Error 1	16	6.8	0.43		
Error 2	24	4.5	0.19		
Error 3	48	5.7	0.12		
Total	119	59.5			

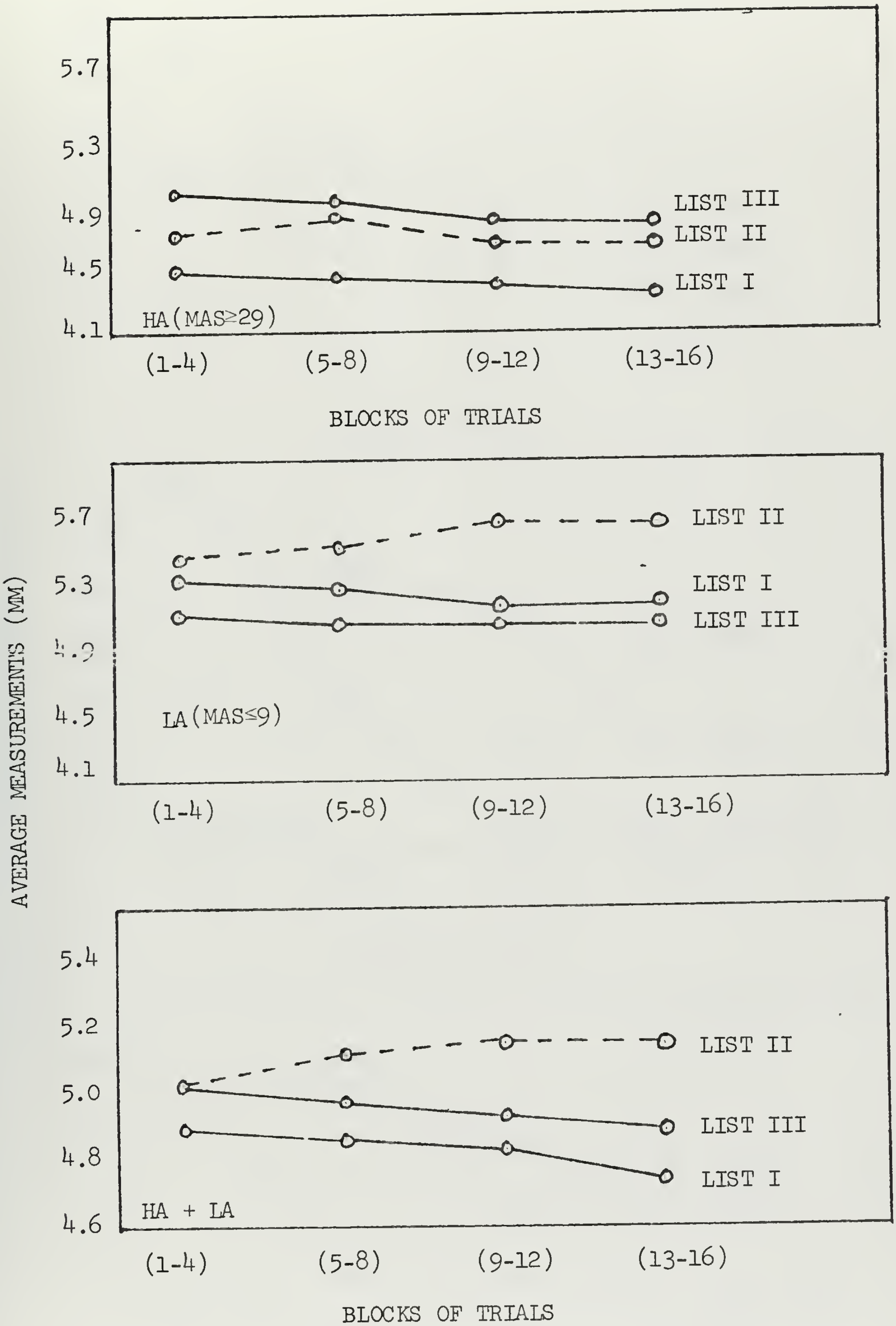

FIGURE 4

Group x Block x List Interaction
For Maximum Diameter Measurements

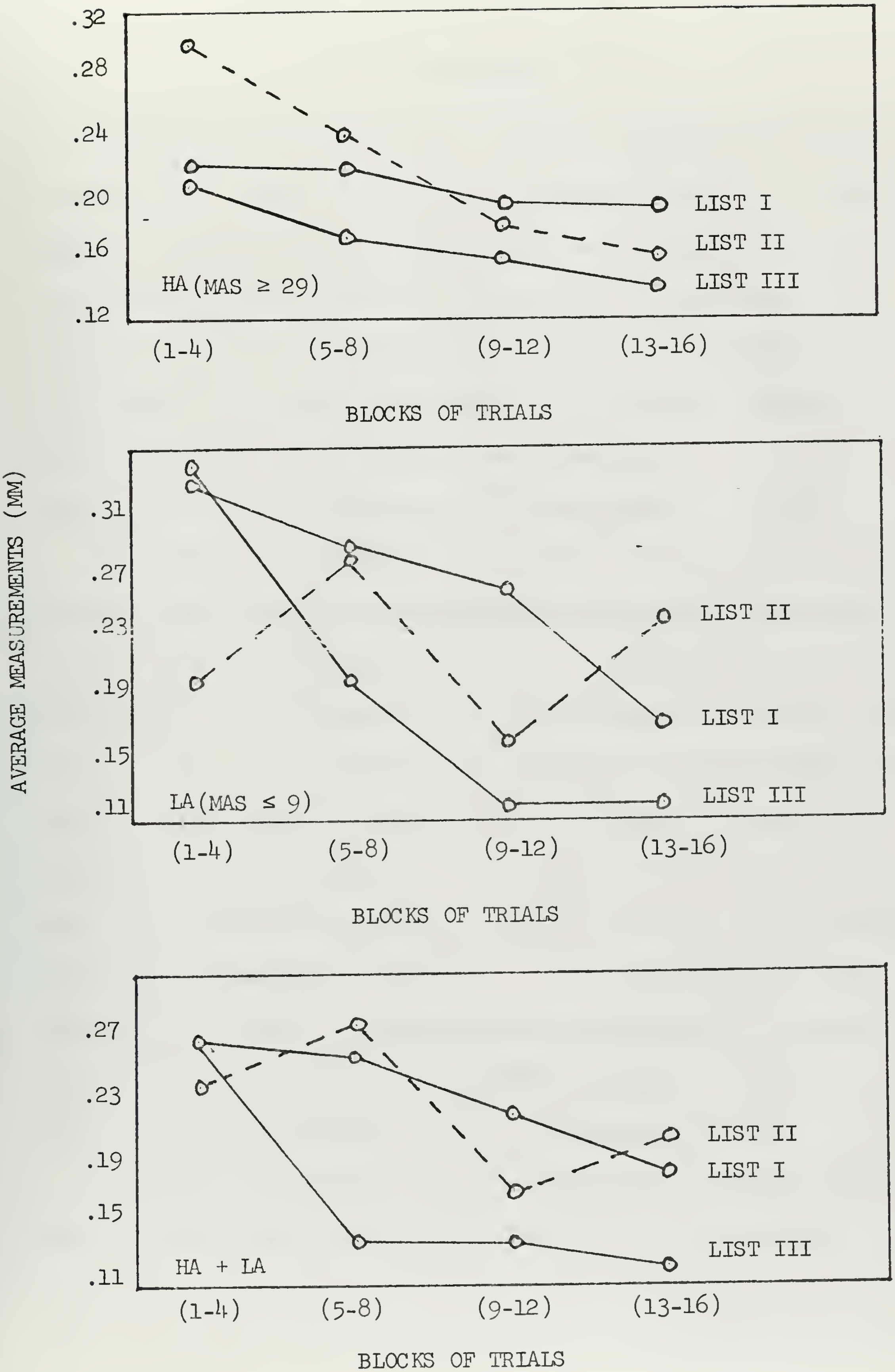

FIGURE 5. Group x Block x List Interaction for Differential Diameter Measurements

IV. DISCUSSION

Despite the attempt to employ a simple cognitive task requiring minimum mental effort as the anxiety provoking situation, a certain degree of increased mental concentration was necessarily exercised by the subjects in their efforts to eliminate the interference of the incongruous stimuli. The influence of this increased mental effort is recognized as a contributing factor of the observed dilation, and as a confounding variable whose effects can only subtract from the total effects which otherwise might be attributable to anxiety.

This confounding variable, however, did not completely occlude the anticipated results as considerable support for a relationship between anxiety and pupillary activity is provided by the data. Particularly the differences of all three measures considered together over all three lists provide strong evidence of anxiety arousal in List II. The differences between List I and List III must be attributed to the persistency of the anxiety effects of List II, as List I and III are of equivalent cognitive difficulty. The increased magnitude of measurements observed for List III are, in addition, contrary to the trend of monotonically decreasing pupil size established for List I. The reversal of this definite trend can only be attributed to the intervening encounter with the incongruous stimuli.

Additional indications of anxiety effects are provided by the specific variational patterns established by the differential measurement. The relative magnitude of this measurement is low for both List I and II. The differentials of the responses to List III,

however, are relatively high. Graphical analysis indicates this large differential occurs as a result of significantly deflated minima, while the maxima deflate much more slowly as a result of persistant anxiety.

The significant interactive effect revealed in the analysis of the differential diameter measurements is shown by the graphical analysis (Figure 3) to occur in parallel with the initial presentation of the incongruous combinations of Block (5-8) of List II. This interaction and the graphical display of the average measurements, Figures 1 and 2, provide support for the hypothesis of increased pupil diameter as a result of the initial encounter with the anxiety provoking situation. Therefore, subject to the assumption that the Stroop color-word interference phenomena produces an anxious condition, we must conclude that this initial dilation is the result of this increased anxiety.

Graphical analysis of the block x list interactions for both the maximum and differential measurements indicates the two MAS groups showed a significant difference in the block x list interaction. Probable causes of this difference are parallel to, and confirm, those discussed above.

With the high degree of variability found to exist between subjects, the possibility of a relationship between the extreme pupillary responses and the extreme MAS rankings should be enhanced. The anticipated result of larger pupil diameter increases for the highly anxious group, however, was found not only to be erroneous, but the observed results were found to be contraindicative of this

hypothesis. The only significant group effect was found in the triple interaction term involving groups x blocks x lists (Figures 4 and 5). Examination of the figures suggests that the group effect for maximum diameter (Figure 4) was due to the difference in the way the LA group reacted to the List II condition, both in elevation of their pupillary responses and in the rising slope of the curve. The group effect for the differential measure (Figure 5) was due, primarily, to the steepness and initial high elevation of the List III curve for the LA group. Several possible explanations of this observation are considered here.

The unalerted encounter with the incongruous color-word combinations may have constituted a sufficiently unpleasant resolution task to qualify the stimuli as "noxious". According to Hess (1965), confrontation with such a stimulus would elicit a pupillary constriction. This explanation is considered here, for in pre-experimental testing several subjects, upon encountering the incongruous color-word combinations at rapid presentation rates, showed a marked constriction of the pupils. Two of these subjects subsequently closed their eyes and turned away from the apparatus, apparantly demonstrating their inability to cope with the situation. This extreme response qualifies as the "ultimate negative response" as discussed by Hess (1965). Such a constriction was possibly effected by members of the highly anxious group and thus diminished the significance of the group effect.

The task difficulty, as previously mentioned, may have elicited a higher degree of mental concentration from the low anxiety group.

This group, which is better conditioned to cope with anxiety, would be more capable of exercising increased mental effort, which would in turn elicit the larger pupillary dilation.

Finally, the requirement of restricted head and eye movement may have inhibited normal modes of anxiety relief common to the low anxiety group. This restriction would have resulted in an overly aggravated situation for the low anxiety group, thus resulting in an overreaction dilation response.

The rather low confidence of the statistically indicated differences can be attributed to the high variability due to the subjects. The problem of high pupillary variability within subjects and its possible misinterpretations are discussed by Woodmansee (1966). In this discussion, the averaging and grouping of data and repeated measures are suggested as means of minimizing the effects of this high variability. The blocking of observations in this study, as earlier discussed, should serve to reduce the influence of this variability.

Utilization of the differential diameters in the analysis was accomplished with the intent of further dampening the effects of the random pupillary fluctuations on the statistical analysis.

As examination of the results outside the formal statistical analysis reveals, the results appear to conform to previously reported results. Particularly, it is observed that following the required verbalized response, there occured a consistent decrease in pupil diameter. This effect, observed throughout the study, has been the object of previous studies (e.g. Simpson and Paivio, 1968).

The very evident decrease in pupil diameter for the homogenous task has also been previously documented (e.g., Beatty and Kahneman, 1966).

The conformity of this data with these previously reported phenomena lend credibility to some otherwise seemingly inconsistent results found in this study.

V. CONCLUSIONS

The attempts to isolate the specific effects of anxiety on pupillary responses must be considered equivocal. The initial encounter with the anxiety provoking situation did, however, produce the anticipated dilation. Anxiety effects were also found to persist after removal of the anxiety inducing stimuli.

The attempt to associate pupillary behaviorial characteristics with MAS implications revealed no clear-cut results of high-low anxiety. The small sample size used in this attempt severely limited the potential results.

Additionally, the high variability due to subjects and the confounding effects of mental effort prevented conclusive establishment of a definite relationship between the task-produced anxiety and pupillary dilation.

The study does serve to underscore the original contention that the complex labyrinth of potential causative factors of pupillary activity make isolation of specific factors exceedingly difficult.

APPENDIX A

WORD LISTS

LIST I and III	LIST II	INK COLOR
5	5	
4	4	
3	3	
2	2	
1	1	
0	0	
BLACK	BLACK	BLACK
RED	RED	RED
GREEN	GREEN	GREEN
RED	GREEN	RED
BLUE	RED	BLUE
BLACK	RED	BLACK
RED	BLUE	RED
BLACK	RED	GREEN
BLACK	RED	BLUE
BLUE	BLACK	RED
RED	BLUE	GREEN
GREEN	RED	GREEN
GREEN	BLUE	BLUE
BLUE	BLUE	BLACK
RED	RED	GREEN
GREEN	BLUE	RED

ALL WORDS CONGRUOUSLY COLORED

APPENDIX B

INSTRUCTIONS

1. This is an experiment to measure eye responses to various stimuli.
2. In the experiment you will be asked to place your chin on the chin rest in the head holder in front of you. Adjustments will then be made to make you as comfortable as possible and to focus the camera. Once this is accomplished, you will be asked to limit head movement as much as possible until completion of the test.
3. You will then be asked to fix your gaze on the open slot on the device in front of you. During the test runs you are asked to identify the color of the ink in which the words are written. The only words which will appear are RED, BLUE, GREEN, and BLACK.
4. Just prior to each run, you will be reminded to identify the color of the ink.
5. You are to make only one response for each stimuli, and this is is to be as quickly as possible, and prior to the appearance of the next stimuli. If you realize that you have made a mistake, forget it.
6. Although you may blink your eyes, it is requested that you try to limit the frequency of blinking.
7. Please do not disclose the purpose of the test or its method to prospective subjects.

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13. ABSTRACT

The Stroop color-word test was used as an anxiety provoking situation, in an attempt to isolate the effects of such anxiety on pupillary behavior. A TV Pupillometer was utilized to measure the pupil diameter during testing. Although the confrontation with the anxiety provoking situation did produce the anticipated pupil dilations, the data was felt to be contaminated by a confounding variable and the high variability attributed to the subjects. As a result, no conclusive evidence was obtained to either support or repute the association of anxiety with the observed pupillary reactions. The results are significant, in that the commonly accepted association of anxiety and pupillary dilations was not supported.

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